Vector Field Visualization of Magnetospheric Dynamics

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Abstract. The 3D magnetospheric plasma flows produced by magnetohydrodynamic (MHD) simulations are often very complex and difficult to analyze. Critical point analysis is an important technique utilized in vector field visualization to represent the important aspects of the vector field topology. We apply critical point analysis and vorticity-based filtering to 3D magnetospheric plasma flows. This technique has enabled space physicists to visualize the complex nature of magnetospheric dynamics for the first time on a global scale.

Introduction and Related Work

In space weather modeling and simulation, the magnetosphere plays an important role in characterizing space weather. Visualizing the complex nature of the magnetospheric dynamics is an important aspect of space weather analysis, which has to a large degree eluded space physicists. The Community Coordinated Modeling Center (CCMC) is developing a 3D visualization tool called Space Weather Explorer (SWX) to aid space science researchers in understanding their simulation data. Currently SWX displays output from the Block Adaptive Tree Solar-wind Roe Upwind Scheme (BATS-R-US), the first model selected for study by the Community Coordinated Modeling Center (CCMC). BATS-R-US is a 3D magnetohydrodynamics (MHD) code developed at the University of Michigan for massively parallel computers using adaptive mesh refinement (AMR) [1].

Critical point analysis is an important technique utilized in vector field visualization [2, 3, 4, 5]. Critical points[1] are points at which the magnitude of the vector field vanishes and can used to accurately represent the important aspects of the vector field topology. Recently Wong et al. [6] proposed a vorticity-based filtering technique to eliminate less interesting and sometimes sporadic critical points in climate simulation wind velocity vector fields that contain a large number of critical points. We apply critical point analysis and vorticity-based filtering to 3D magnetospheric plasma flows produced by BATS-R-US. Parnell et al. [7] provides the physical theoretical structure of 3D magnetic neutral points.

Results

One study currently being conducted by CCMC physicists is the effects of a solar wind pressure pulse on the earth's magnetosphere and ionosphere [8]. The BATS-R-US simulation was run for 78 time steps on 128 processors and used 2.2 million cells. The pressure pulse triggered fast magnetic reconnection in the magneotail and the formation and ejection of plasmoid in the tail. SWX found roughly 100 critical points per time step. Visualizing the streamlines for each of the critical points often leads to cluttered results. Therefore, a user-controlled percent of the critical points with the smallest magnitude of the magnetic field vorticty are eliminated. We have found that approximately 20% of the critical points can be eliminated in this manner without losing any key features of the magnetosphere topology. Figure 1 illustrates the results of using critical point analysis to visualize the magnetic field of two time steps in our simulation. Here, 20% of the critical points have been eliminated using vorticity-based filtering. The critical point analysis feature of SWX enables the CCMC physicists to visualize the complex nature of this phenomenon for the first time on a global scale.

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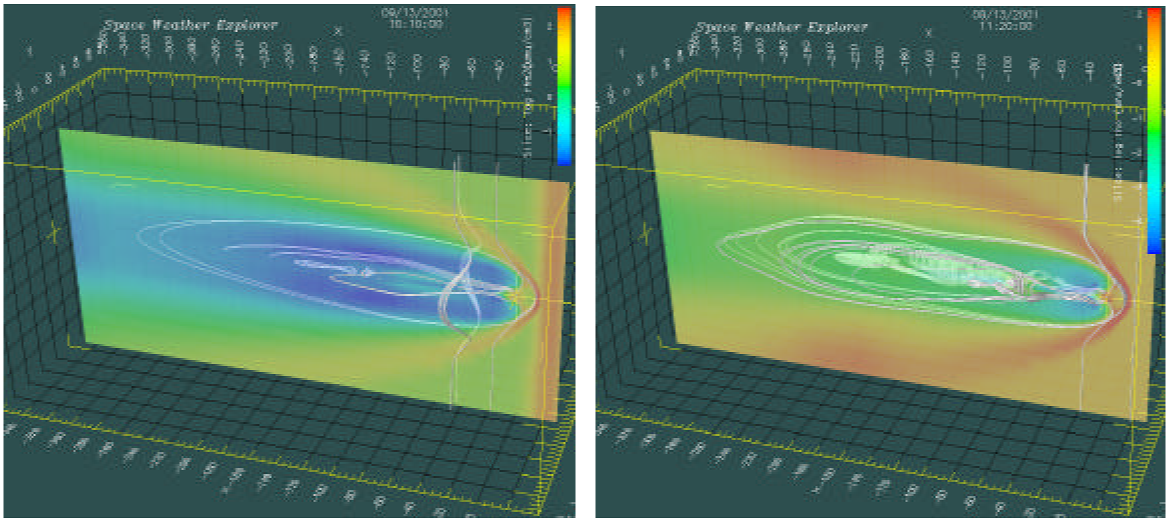
[1] Plasma researchers refer to critical points as neutral points.



(a) **(b)**

Figure 1. Visualization of magnetospheric dynamics using critical point analysis. (a) The nearly steady state of the magneotail just prior to the arrival of the pressure pulse. (b) The state of the magnetotail near the end of the simulation after the pressure pulse has passed through the tail. The loop-like magnetic field lines indicate the position of the core of the ejected plasmoid. Complicated magnetic field singularity can be clearly identified at the near-earth reconnection site. Magnetic turbulence is also seen in the post-plasmoid plasma sheet.

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